Volcanic forcing in decadal forecasts of surface temperature

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Context

Volcanic eruptions can significantly impact the climate system, by injecting large amounts of particles into the stratosphere. By reflecting backward the solar radiation, these particles cool the troposphere, and by absorbing the longwave radiation, they warm the stratosphere. This radiative forcing can decrease the global mean surface temperature by several tenths of degrees. However, large eruptions are also associated to a complex dynamical response of the climate system that is tricky to understand considering the low number of available observations. Observations seem to show an increase of the positive phases of the Northern Atlantic Oscillation (NAO) the two winters following large eruptions, associated to positive temperature anomalies over Northern Eurasia (Driscoll et al., 2012). The current generation of climate models struggle to forecast the climate response to large eruptions, as it is both modulated by, and superimposed to the climate background conditions, largely driven themselves by internal variability at seasonal to decadal scales (Zanchettin et al., 2013). Here, we evaluate the skill of the EC-Earth model (Hazeleger et al., 2012) to forecast the climate response to eruptions. We differentiate the impact of the last 3 major eruptions (Agung, March 1963, El Chichon, March 1982 and Pinatubo, June 1981) from the natural variability by comparing simulations with and without volcanic forcing. Large eruptions significantly cool the surface, in particular in the tropics and over large parts of continental areas during the 3 years following the eruption (Fig. 1). We also model a significant warming in Northern Eurasia and in Western Antarctica occurring 3 years after the eruption, potentially due to atmospheric circulation changes. This work shows the added value associated to volcanic forcing in climate simulations devoted to seasonal to decadal forecasts. It is a first attempt to design models able to forecast climate response to the next large volcanic eruption.

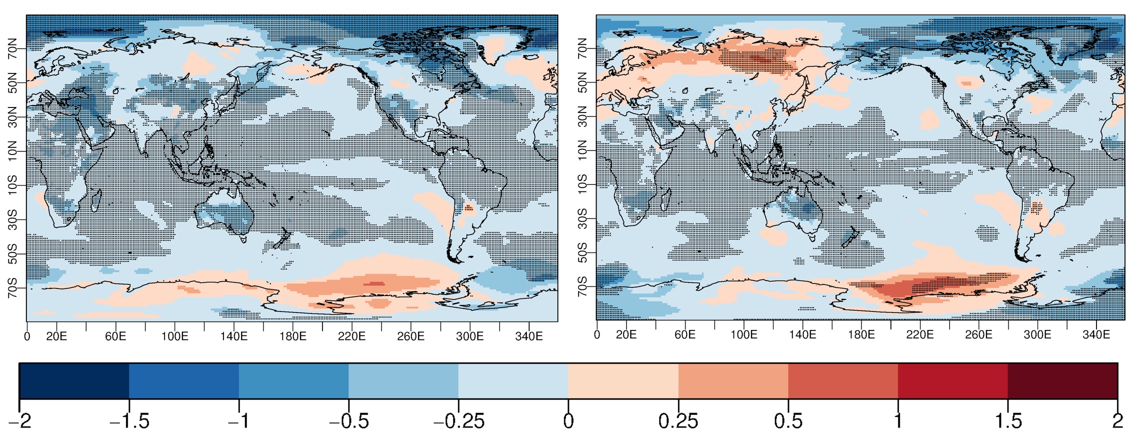

Figure 1: Surface temperature difference (°C). 3-year average after the 3 last major eruptions (Agung, 1963, Chichon, 1982 and Pinatubo, 1991). Difference has been computed between two 5-member hindcasts, one including and another excluding volcanic forcing of large eruptions, and appears shaded when significant with a 5% level.

Climate response to volcanoes

Both initialisation and volcanic forcing need to be taken into account when forecasting global temperature after an eruption (Fig. 3). Volcanic forcing induces a significant cooling, in particular after the Pinatubo eruption. Initialisation allows the model to fit the observation at the beginning of the forecast. However, The EC-Earth model does not adequately reproduces the inter-annual variability associated to ENSO events. In particular, our initialised simulations do not catch the strong Niño event occurring after the El Chichón eruption.

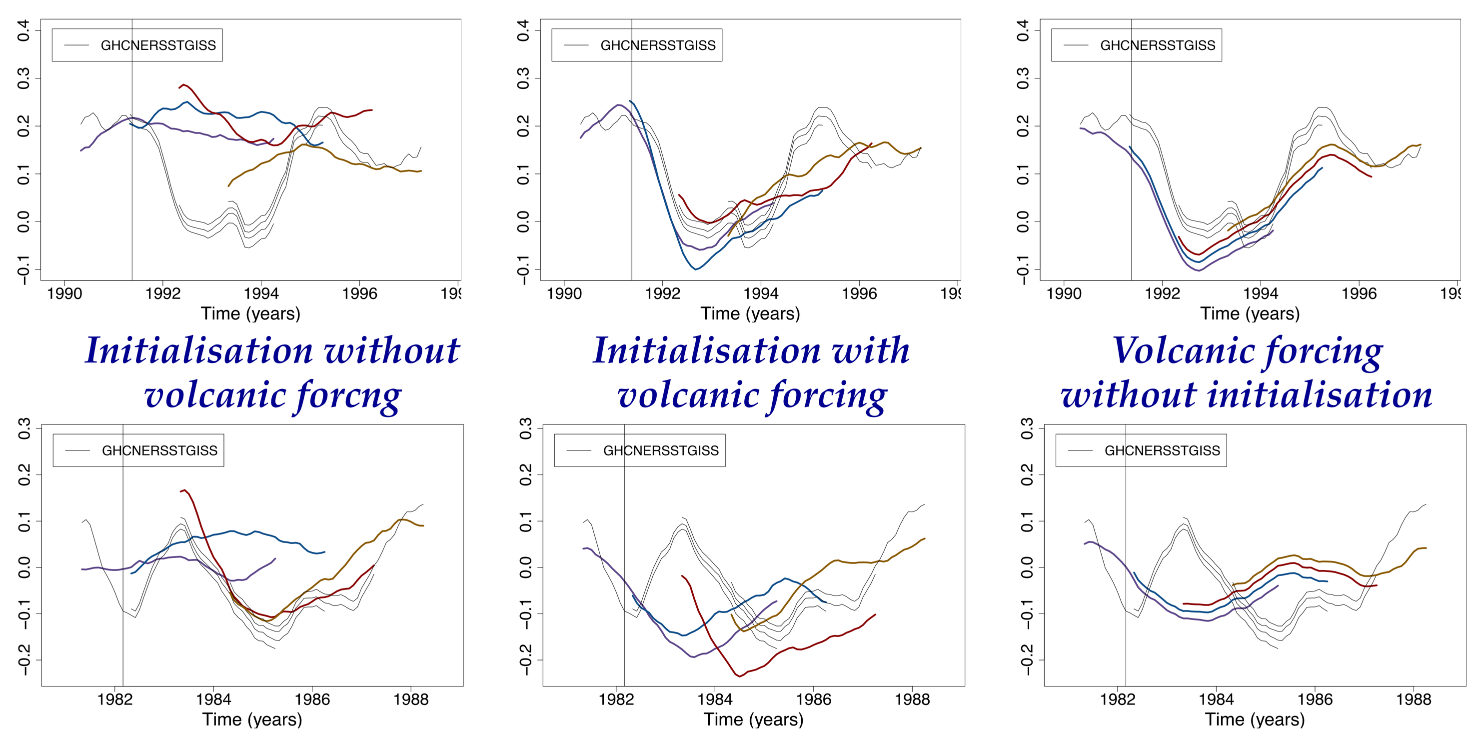

Figure 3: Surface temperature anomalies forecast for 4 start dates around eruptions (blue and purple start before the eruption; red and yellow start after). Hindcasts start in November. Observations anomalies (black) are computed with climatologies varying along the forecast time, data from GISS centre (GHCNERSSTGISS). Anomalies are smoothed with a 12-month running mean. Vertical bar shows the date of the eruption.

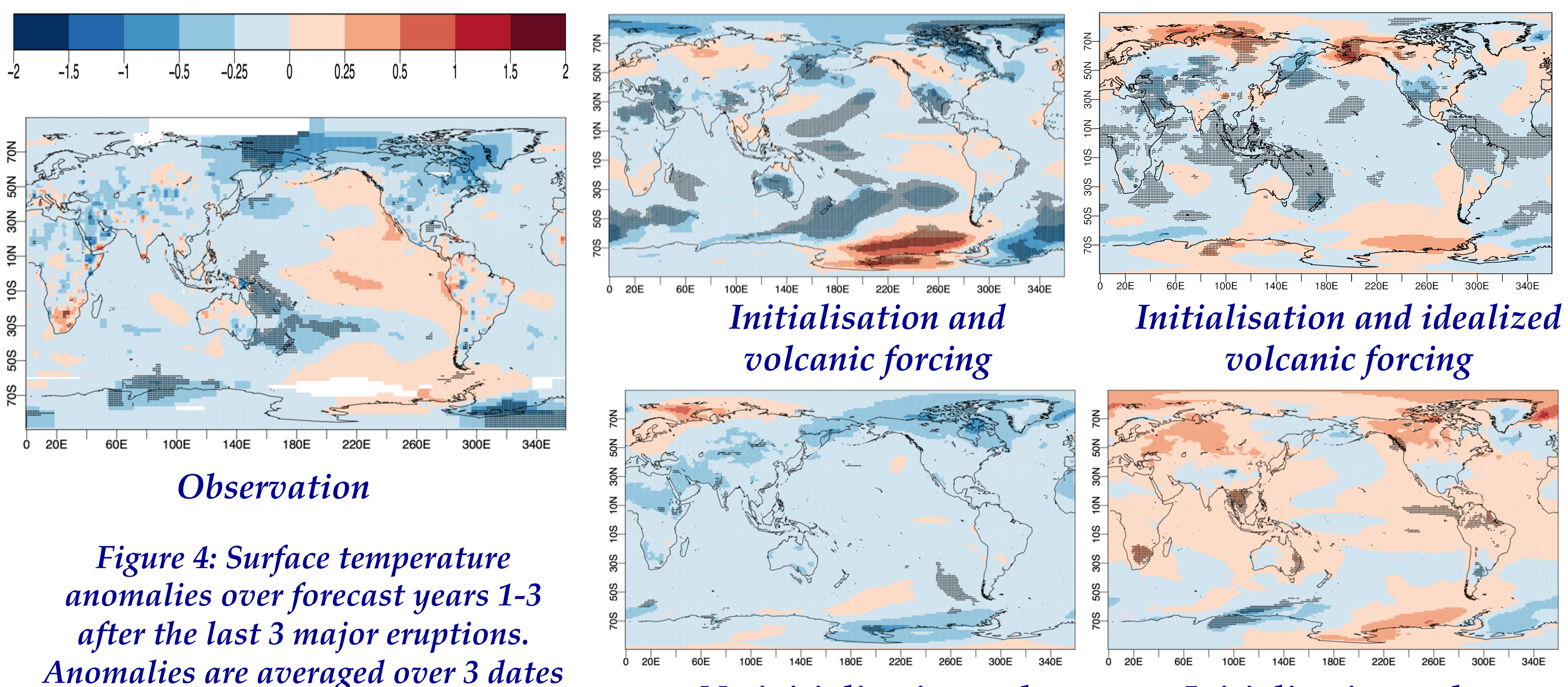

Figure 4: Surface temperature anomalies over forecast years 1-3 after the last 3 major eruptions. Anomalies are averaged over 3 dates (and 5 members for the simulations).

The hindcast performed with initialisation and volcanic forcing reproduces the significant cooling observed in the Western Pacific, in the Southern Ocean and the Arctic Ocean (Fig. 4). This is not the case of the simulations without initialisation or without volcanic forcing. The simulation based on the idealized forcing shows a cooling in the tropics but fails to reproduce the cooling occurring at middle to high latitudes.

Surface temperature in winter 1 is well simulated, with a strong ENSO signal mixed with the volcanic signal (Fig. 5). Our model also reproduces the tropical cooling occurring in winter 2 and 3. The significant warming observed in Northern Eurasia in winter 2 is badly forecasted. Such anomaly, potentially induced by dynamical effects appears in our forecast in winter 3.

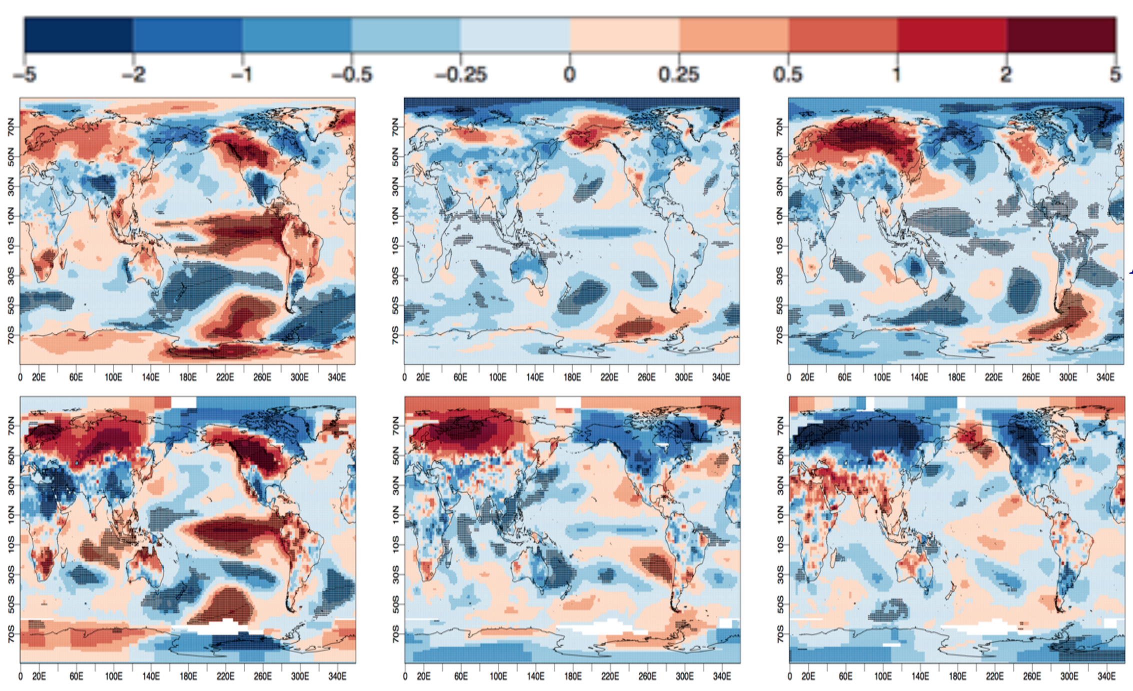

Figure 5: Winter surface temperature anomalies after the last 3 major eruptions. Anomalies are averaged over 3 dates (and 5 members for the simulations). Top: forecast; bottom: observations

Modelling the climate response to volcanoes with EC-Earth

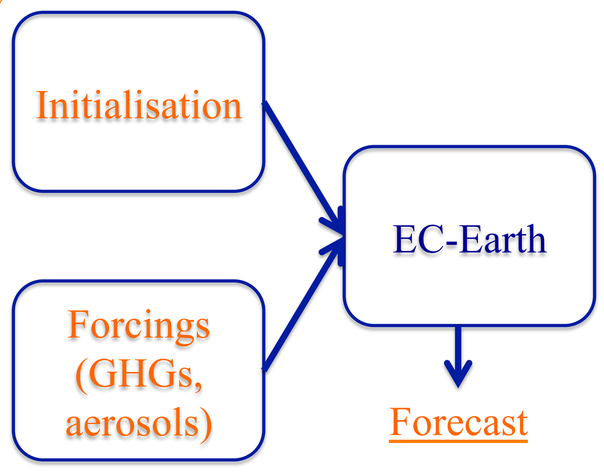

Figure 2: Description of EC-Earth model used as a forecast system

We used the EC-Earth ocean-atmosphere coupled model to run decadal hindcasts, i.e. forecasts over the last decades (1961-2001), using observed forcing and initialised from observations. We performed 5-member sensitivities experiments:

→ **Simulations with/without initialisation**

→ **Simulations with/without volcanic forcing**

→ **Simulations with idealized volcanic forcing** (Exponential decay of stratospheric aerosol load)

Skill related to volcanic forcing

Forecast skill for global temperature increase when including volcanic forcing in the simulations (Fig. 6). The use of initialisation increases the skill only over the first forecast year. The simulations based on the idealized volcanic forcing show higher skill than simulations performed without any volcanic forcing during the first year. Considering the temperature running means over 36 months, these two sets of simulation show similar skill.

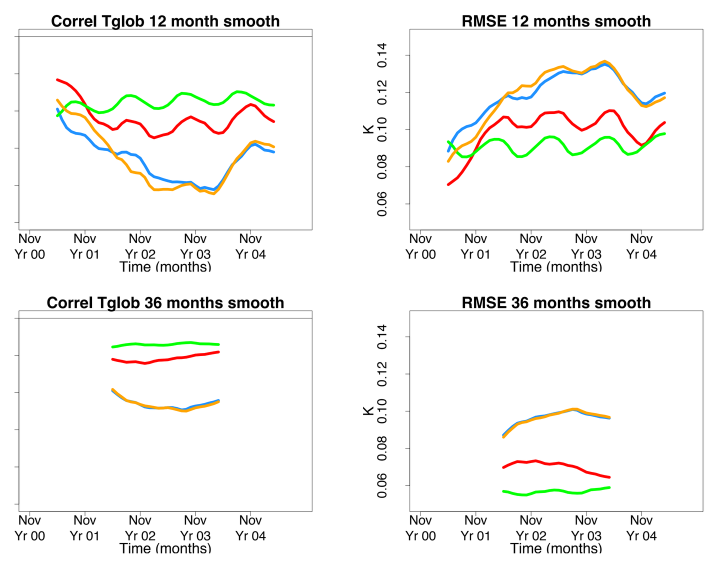

Figure 6: Correlation and RMSE for 12 and 36 month smoothed running mean anomalies. Differences between hindcasts are not statistically significant.

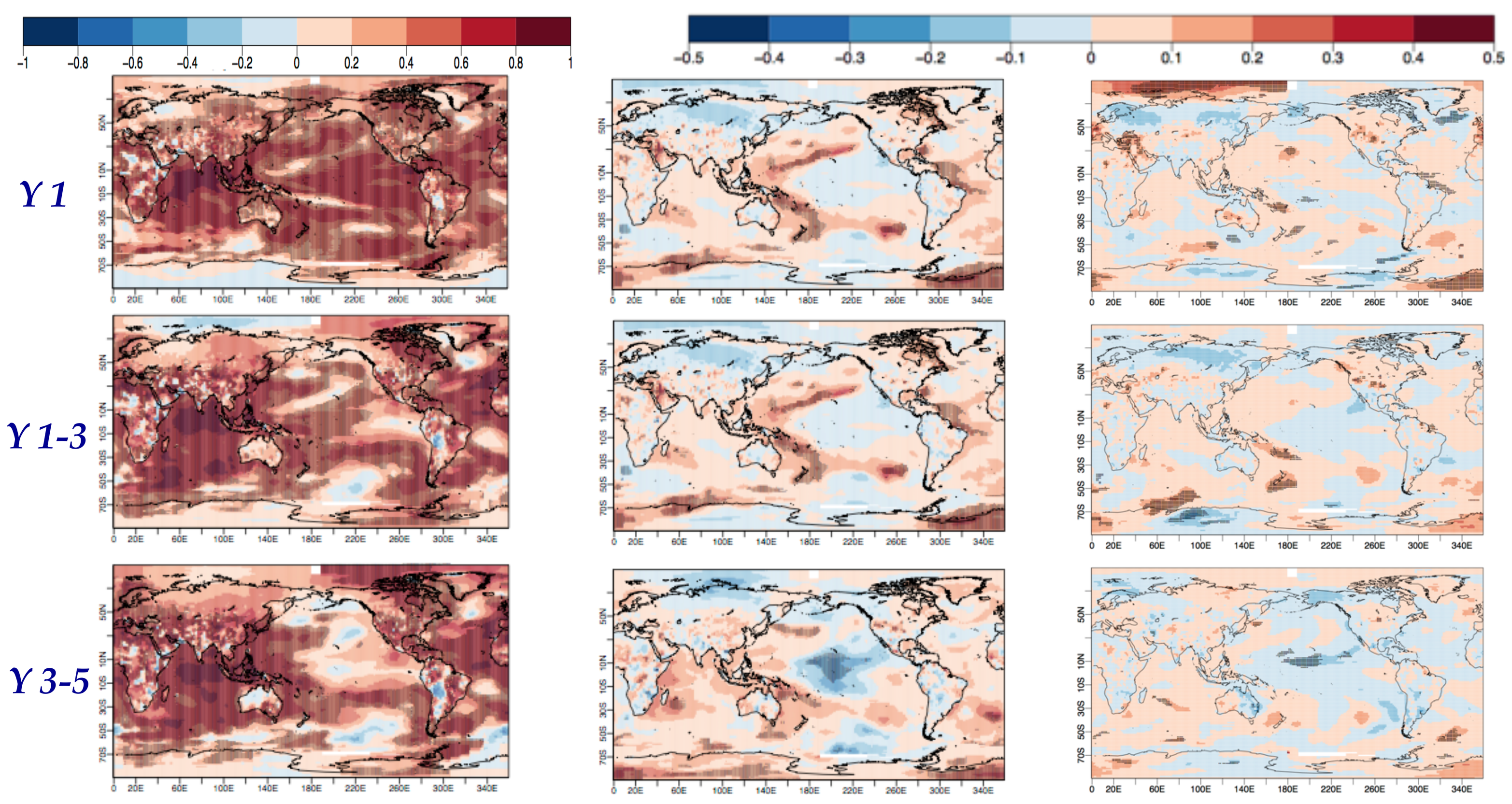

Figure 7: Correlation between forcast and observations.

The forecasts show high skill over Indian Ocean, Tropical Atlantic, Western Pacific and North American Arctic (Fig. 7, left). Parts of the skill are related to the volcanic forcing (Fig. 7, middle). The skill gain obtained with the idealized forcing has a similar pattern to the gain obtained prescribing the observed forcing (Fig. 7, right), although with lower values, suggesting that our idealized forcing is too weak.

Conclusions and outlook

Climate models are useful tools to investigate the climate response to volcanic eruptions, since observations are too scarce to correctly differentiate volcanic signal from climate internal variability. Sensitivities experiments showed that most of the cooling occurring after volcanic eruptions concerns the tropics and large parts of continental areas. The dynamical link between warming that can occur after eruptions, in particular in winter over Eurasia, is not fully established and remains challenging to understand, both with models and observations. This work shows that a significant part of the skill got with current forecasts system is related to the use of observed volcanic forcing that is not available for real-time forecasts. We implemented into our model an idealized forcing that could be used for seasonal to decadal forecasts in the context of a future large eruption. New representations of such idealized volcanic forcing are currently tested.

References

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